

Environmental Effects of Dredging Technical Notes



Potential Application of Geosynthetic Fabric Containers for Open-Water Placement of Contaminated Dredged Material

Purpose

The purpose of this technical note is to summarize the present state of knowledge on the use of geosynthetic fabric containers (GFCs) for placing contaminated sediments in open water, describe their benefits and potential applications, and identify issues of concern.

Background

Cost-effective placement of contaminated dredged material (assumed to be silt- and clay-sized material) is a major problem in many locations. Capping is one of several options that can be applied to the problem. A major limitation of capping projects is the thin (less than 100- to 150-mm-thick), wide (100 to 400 m) apron that forms during conventional bottom dumping of fine-grained material from split-hull barges. Locating sufficient cap volume and the cost of placing the additional capping material to cover the apron are significant problems for many capping projects. The spread of the contaminated sediment apron also poses potential problems for retaining contaminated material inside the placement site.

Another problem in disposing of contaminated dredged materials is potential water column impacts. While, in general, water quality is not a problem during conventional placement of contaminated dredged material from split-hull barges, in some cases limited mixing zones or stringent water quality standards will cause the placement process to fail state water quality standards or U.S. Environmental Protection Agency requirements.

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Containing the contaminated sediments in GFCs for subsequent placement from split-hull barges offers the potential to eliminate the apron, thus substantially reducing the volume of cap material required and reducing the potential for contaminated sediments to extend beyond the site boundary. GFCs also have the potential to eliminate water quality problems at the disposal site by essentially eliminating the loss of fine sediment (silt- and clay-sized) particulates and associated contaminants to the water column. The magnitude of the contaminated sediments problem is such that considerable interest has been generated concerning application of GFCs for open-water placement of contaminated dredged material. In this technical note, when referring to sediments, the terms "fines" and "fine-grained" will follow the American Society for Testing and Materials (ASTM) and Unified Soils Classification System (USCS) definitions of fine-grained sediments—those passing the No. 200 sieve (0.074 mm), that is, silts and clays.

Additional Information

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The GFC Concept

Figure 1 illustrates the concept of barge placement of GFCs filled with dredged material. The major steps in the operation are as follows:

- a. The barge (which often requires modifications) is lined with the appropriate geosynthetics.
- b. Dredged material is placed (either mechanically or hydraulically) into the lined barges.
- c. For mechanical placement, the geosynthetic fabric flap is folded over the dredged material and sewn closed, forming the GFC.
- d. The GFC is released from the barge at the placement site.

Potential Benefits of GFCs for Placement of Contaminated Sediments

Contaminated dredged material may be defined as material that is unsuitable for unrestricted open-water placement. Materials can be unsuitable from the standpoint of potential water column impacts (both at the dredging and disposal site), where water quality standards or criteria are not met. Water column impacts are not usually a concern during placement for most materials from navigation dredging projects, unless stringent standards are imposed or unless the allowable mixing zones are tight. So, potential benthic impacts are

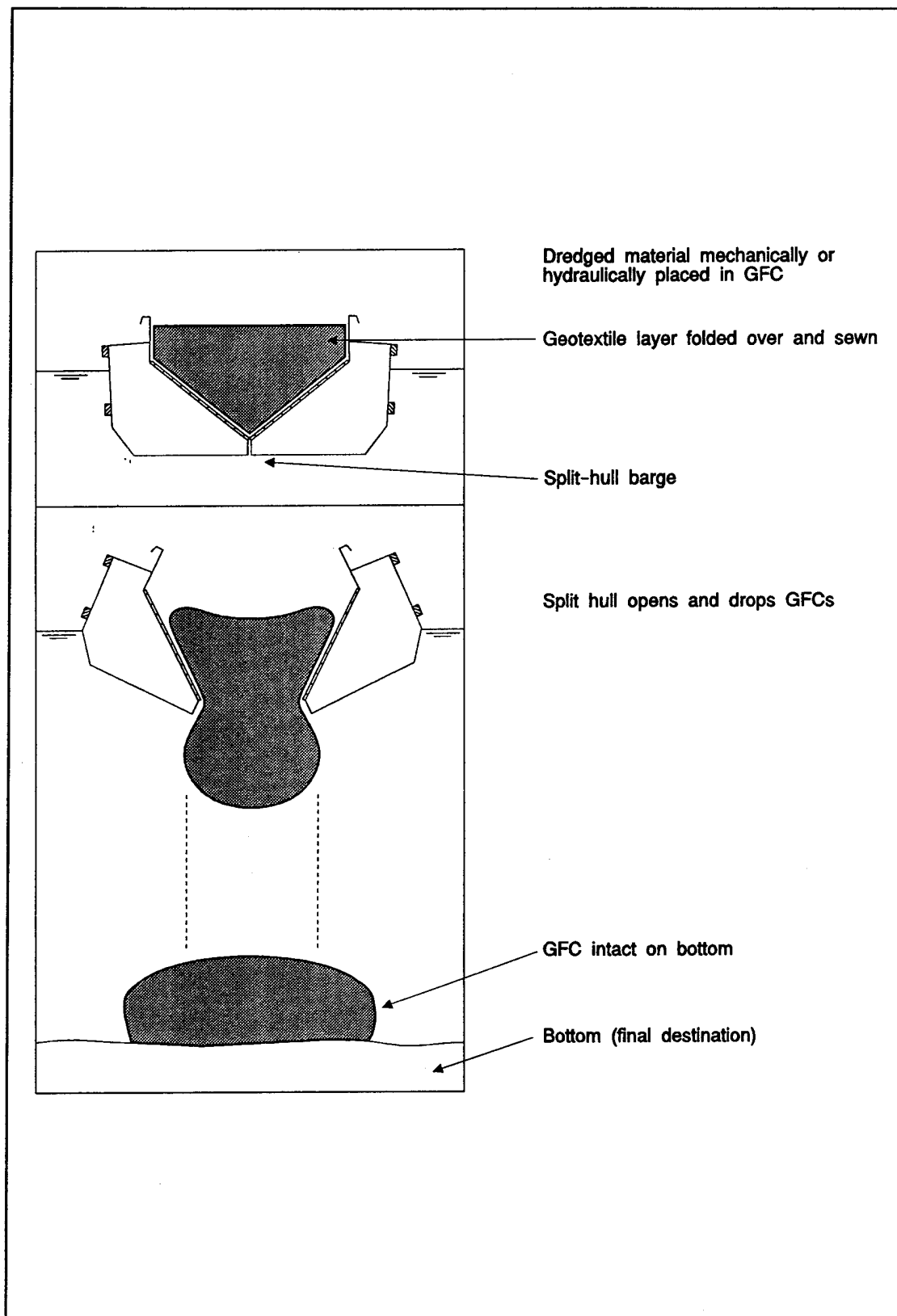


Figure 1. Concept for barge placement of geosynthetic fabric containers (GFCs)

the normal concern for most contaminated sediment placements from navigation projects. Capping, the covering of the contaminated material with a layer of clean material, may be considered as a control measure for potential benthic impacts.

GFCs have potential application for open-water placement of contaminated dredged material from two standpoints. First, GFCs can act as a control measure to reduce water column impacts. Second, the GFCs can reduce the degree of spread of the material on the bottom, which can be advantageous for capping. In fact, GFCs could eliminate the requirement to cap, though a considerable amount of investigation would be required along with other special considerations (for example, deep water, low biological activity, etc.). To understand how the GFCs may be beneficial, it is first necessary to examine the behavior of a conventional dredged material discharge from a barge or scow without containers.

Bucket or clamshell dredges remove the sediment being dredged at nearly its in situ density and place it in a barge or scow for transportation to the disposal area. Although several barges may be used so that the dredging is essentially continuous, placement occurs as a series of discrete discharges from the barge or barges. Barges are often designed with a split hull, which opens within a matter of tens of seconds, and the contents may be emptied within tens of seconds, essentially as a discrete discharge. Some fraction of the dredged material may be stripped away during its descent through the water column, and ambient water is entrained with the discharge, reducing its density.

The use of GFCs can reduce the dispersion of dredged material fines to the water column and can reduce the volume of water entrained during descent. The presence of the fabric essentially acts as a filter cloth in containing dredged solids while allowing excess water to pass through the fabric. Also, the fabric inhibits the entrainment process during descent. The reduction in entrained water results in a reduced volume of dredged material fluid fraction discharged to the water column. Use of GFCs would therefore potentially aid in meeting water quality standards or water column biological criteria for projects with stringent standards or small allowable mixing zones.

The use of GFCs would also reduce the potential spread of material on the bottom upon impact. Spreading would be limited to the elliptical configuration of the bag, with the fabric effectively preventing any larger spread and any formation of a thin apron. This reduction in footprint size could have a benefit for capping applications by reducing the volume of capping material required.

Theoretical and model studies, as well as field data, will be necessary to confirm the relative advantages of containers over conventional open-water discharge for specific site conditions and material characteristics.

Conceptually, using GFCs as part of capping projects appeals to many people. The idea of confining the contaminated material in GFCs to eliminate or

greatly reduce the losses of silt- and clay-sized particles and associated contaminants to the water column during placement (and to eliminate resuspension of contaminants during subsequent placements, during capping, or during a storm prior to capping) is appealing from an environmental standpoint. The need for less cap material can reduce capping costs and make more projects feasible in situations where suitable cap material is limited.

However, it should be noted that the Corps has performed nearly 30 capping projects using conventional hopper or barge surface-release techniques. No adverse environmental impacts have been documented, even though some losses to the water column and resuspension have occurred.

The decision to use GFCs for a capping project should therefore be justified based on economics (that is, they will lower overall project cost) and on environmental benefits. Potential advantages of using GFCs include increased site capacity, preventing material from moving offsite, and in some cases, meeting stringent water quality standards. An arbitrary decision to use GFCs for any capping project without thorough documentation of the benefits versus costs should be avoided. To allow informed decisions to be made concerning whether to use GFCs for a specific project, the following information on GFCs is presented. First, some basic information on GFCs and how they are actually used on a project is provided. Next, summaries of field applications of GFCs at Red Eye Crossing and Marina Del Rey are presented. Discussions of how GFC use impacts the various aspects of capping projects (as compared to conventional open-water placement) are also presented. The unknowns associated with use of GFCs for capping projects are described, along with required research.

Prior Experience with GFCs

Geosynthetic fabrics have been used in construction of confined disposal facilities (CDFs) for years. For CDF applications, geosynthetics have been used as liners, to help stabilize dikes, and to accelerate consolidation of sediments. GFCs filled with sediments have been placed submerged in aquatic environments since 1973. A considerable number of applications have used GFCs as shallow-water, low-energy breakwaters and as dikes to contain dredged material (Landin, Fowler, and Allen 1994; Garbarino and others 1994). Fully submerged GFCs have been used in deeper water with projects in the United States, Holland, and Japan, with most experience from European projects. For example, the Dutch used GFCs in a waterway to stabilize a bank (Fowler and Sprague 1993). Fowler, Sprague, and Toups (1995) discuss past experience with GFCs, with particular emphasis on Corps projects.

In the United States, GFCs have been used for the placement of uncontaminated dredged material on a U.S. Army Engineer District, New Orleans, project at Red Eye Crossing on the Mississippi River near Baton Rouge, LA. At this site, geosynthetic fabric bags (small GFCs containing only a few cubic meters of material) and GFCs were filled with sand and used to create soft dikes

to channel riverflow, for the purpose of reducing sedimentation (Duarte, Joseph, and Satterlee 1995). To date, the only aquatic placement of contaminated dredged material using GFCs occurred during a project for the Corps' Los Angeles District. In this project, contaminated sediments from Marina Del Rey in Venice, CA, were contained in GFCs and placed in a shallow-water habitat in the Port of Los Angeles (Fowler and others 1995b, Mesa 1995).

GFC Material and Construction

Geosynthetic fabrics are tough flat sheets consisting of synthetic fibers (such as polypropylene, polyethylene, and other polymeric materials) that can be woven, knitted, or simply pressed together. Woven and knitted sheets are termed "woven geotextiles," and sheets that are pressed, matted, or punched together are termed "nonwoven geotextiles." The sheets are resistant to corrosion and degradation from biological activity because they are made from synthetic materials. Many geotextiles are available in sheets, 5 to 8 m wide, which are easily sewn together to allow the construction of composite systems to perform specific functions. A major advantage of geotextiles is that they are pervious to water flow both across and within their manufactured plane. They are used in the construction industry to achieve some combination of reinforcement, drainage, separation, and filtration.

The use of geosynthetic fabrics (also called geotextiles) has risen steadily in the United States since about 1977. Geosynthetics, in general, and geotextiles, in particular, have come into such widespread use that the ASTM has established Committee D-35 to standardize techniques and procedures within the industry.

GFCs are formed by sewing together long sheets of geosynthetic fabric. Depending on the grain size of the dredged material, GFCs can consist solely of an outer strength layer to contain sand-sized particles. For dredged material with substantial amounts of silt- and clay-sized particles, an inner liner may be required to prevent migration of these finer particles. Together, the outer strength layer and inner liner may act as a system providing even greater resistance to rupture and filtering capabilities.

The outer strength layer of the GFCs is usually made of woven polypropylene and/or polyester yarns that are sewn together. Typically, the final shape after sewing is a cylinder or rectangular box. During filling, the GFC assumes the shape of the barge or other confining structure. When the GFC is resting on the bottom, it is nearly elliptical in shape. Seam strength is usually the limiting design factor from a strength standpoint. In woven outer layers, fabric strengths of about 175 to 193 kN/m (1,000 to 1,100 lb/in.) are possible, with seam strength about 50 to 60 percent of that value depending on the type of seam used and the machine used to do the sewing. Seams formed in the factory on large fixed machines can achieve strengths of 88 to 105 kN/m (500 to 600 lb/in.), while seams done in the field with hand-held sewing machines can be as low as 44 kN/m (250 lb/in.).

If a liner is required to reduce the migration of clay- and silt-sized particles and associated contaminants to meet water quality standards, the liners used are nonwoven fabrics that act as a filter. Liner fabric strengths range from about 35 to 75 kN/m (200 to 400 lb/in.). With the proper seam, seam strengths equal the fabric strength of nonwoven fabrics are possible.

ASTM has a number of standards that prescribe geosynthetic fabric requirements (Duarte, Joseph, and Satterlee 1995), including tensile and seam strength (ASTM D 4595) and apparent opening size (ASTM D 4751).

Stresses During Placement

Fabric and seam strength are critical because one of the major concerns associated with GFC use is their integrity during placement. It might be expected that the maximum stresses in the lining of the GFCs would occur when the GFCs impact the bottom; however, because GFCs are filled to less than full capacity (typically about 70 percent capacity), the stresses of bottom impact are not as great as those that occur when the GFCs exit the barge.

Figure 2 shows the simulated sequence of events associated with the exit of the GFC from a split-hull barge. When the GFC is partially out of the barge, maximum stresses occur when the submerged weight of the sediments (between 1.7 and 8.7 kN/m³, plus any water in the barge above the GFC, about 10 kN/m³) is supported by the fabric. The stresses in the fabric are caused by the pressure from the column of sediment in the GFC acting on the unsupported area, equal to the width and length of the split hull opening. Strain gauge testing done at Red Eye Crossing showed that stresses from bottom impacts were only about one third the stresses experienced during exit of the GFC from the barge. It is important for the containers to quickly exit the barge without hanging up. Properly designed containers should exit the barge in 1 to 4 min or less. Exit of the containers can be facilitated by a wide, quick hull opening, low friction between the containers and barge hull (liners can be used), and low strength of sediments in the containers. After the containers exit the barge, they quickly reach a terminal velocity of about 4 m/sec, in 1 sec or less.

Efficient exit of GFCs from the barge is a concern that needs research. The few model tests that have been performed at the U.S. Army Engineer Waterways Experiment Station (WES), with GFCs filled with sand and silt, have indicated that additional tests with a variety of sediments, geosynthetic fabrics, liners fabrics, barge configurations, etc., are needed to optimize the operational aspects. A computer program, which was originally developed to simulate rock scour processes and uses the distinct element method (Palmerton 1980, 1984), has been modified by the WES Geotechnical Laboratory to predict whether the GFC will exit the barge and to determine the tensile forces in the container. The program successfully modeled the container that seized during barge exit, as well as the subsequent successful deployments at Marine Del Rey. This computer program has also been used to simulate hydraulic filling of the GFC

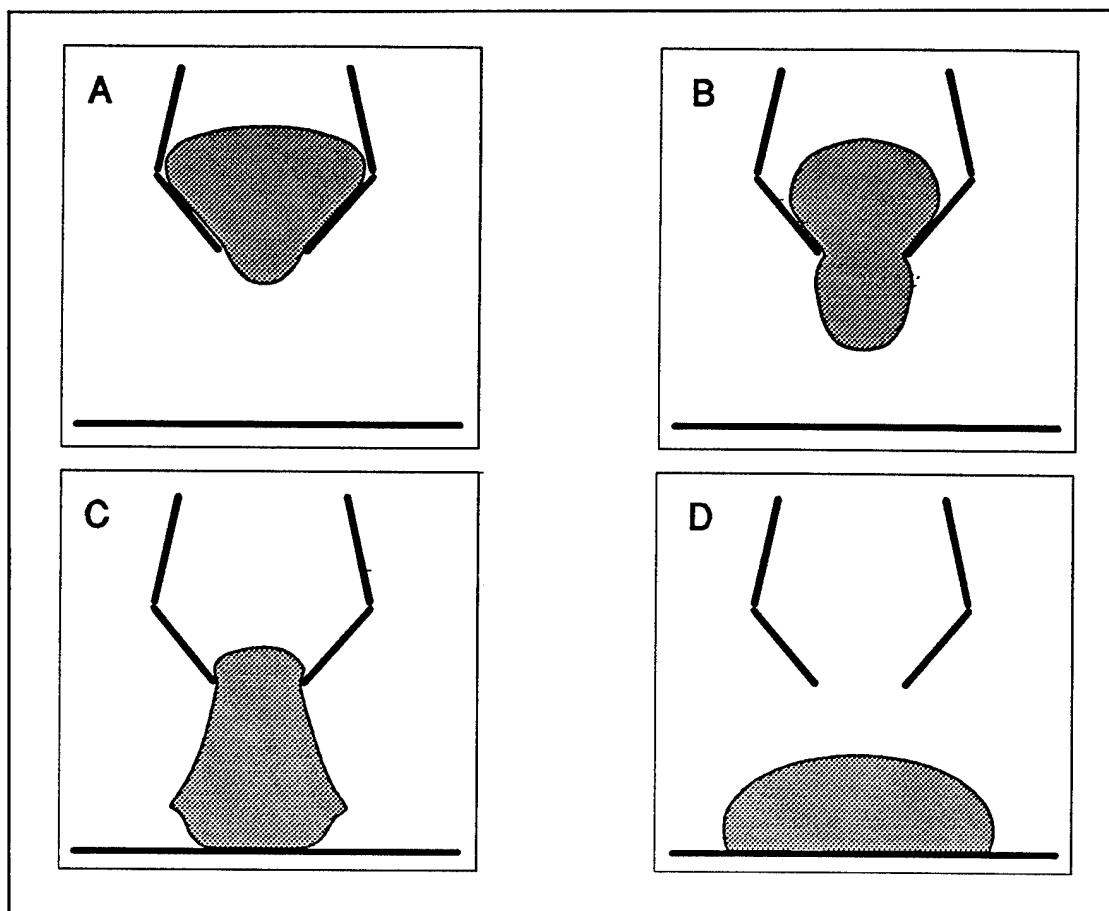


Figure 2. GFC exiting from a split-hull barge

and has been enhanced to simulate the interaction of multiple fluid-filled membranes (flexible or rigid).

Migration of Fines and Contaminants

In addition to the concerns of GFC integrity and effective exit from the barge, the other major area of concern is the ability of the GFC to prevent the migration of fines and contaminants. The ability of the fabric to retain material of a given grain size is related to the apparent opening size (AOS) of the fabric. AOS is defined as that property which indicates the approximate largest particle that can pass through a geotextile. The AOS of high-strength woven polyester fabrics that typically have been used range from about 0.2 to 0.6 mm (which corresponds to standard U.S. sieve sizes of 70 and 30, respectively).

A procedure for determining AOS is outlined in ASTM Designation D 4751 (dated 1994). The procedure involves shaking 50 g of glass beads of a given size against a geotextile that is stretched taut across a circular opening at the bottom of a pan. The AOS is the smallest size of bead that will pass through

a geotextile if 5 percent of the total weight of glass beads in the pan passes through the geotextile after 10 min of shaking.

The behavior of glass beads penetrating geotextiles in a dry vibrating environment is very different from that of soil particles (with nonspherical shapes) being carried in suspension in water. It is known from experience that the AOS of a geotextile decreases as soil particles "blind off" areas through which particles may pass. However, specific research is needed to determine the mechanism of blinding, and how AOS changes with time, soil characteristics, and thickness of geotextile.

The WES Environmental Laboratory (EL) has performed limited tests on the ability of GFCs to contain sediments and contaminants. Sediment samples, when dropped in geosynthetic bags, were found to release a small amount of fine-grained material. As part of the Marina Del Rey project, EL also performed limited testing to determine the concentration of heavy metals, water, and sediments (fine sand with 7 to 8 percent silt and clay) lost through the geosynthetic fabric. During the tests, the geosynthetic fabric was placed in a funnel, the sediments were added, then a vacuum was applied to determine if any fines or contaminants would be pulled through the fabric and liner. However, the tests were not reproducible, and were not intended to simulate field conditions. The GFCs and liners filter the materials by forming a cake on the inside. The vacuum method probably does not simulate cake formation realistically. Centrifuge testing or perhaps small-scale tests may provide better information. Standard tests on contaminants in pore water may also be applicable to the geosynthetic containers. Data on both short-term releases of fines and contaminants (during loading, transportation, and placement) and long-term releases (days, months, years) are needed. Thus, to make defensible statements on the ability of GFCs to retain fines and contaminants for projects where water column impacts are a problem or where containers would be used without caps, a considerable amount of research is required.

Logistical and Operational Considerations

With conventional dredging it takes about 10 to 15 min to bring the empty barge alongside the dredge and secure it. Then, dredging can start almost immediately at full production rate.

Use of GFCs makes the dredging and placement process considerably more complicated than with conventional dredging and placement. First, a facility is needed to prepare and assemble the containers. Following assembly, the containers are taken out to the work barge. The empty scow is brought to the work barge (usually adjacent to the mechanical dredge). The dredge's bucket crane is then used to pick up the container from the work barge and place it in the empty barge. The container (or containers if a liner is used) is then laid out in the barge, requiring a crew of about eight people to unfold and tie down the container(s) so they do not get dragged into the barge during filling. This process can take 1 to 2 hr under the best of conditions. Following filling,

the flap on the container is pulled over the opening and sewn closed with large, hand-held sewing machines. This process can take 30 min to 2 hr, depending on the container size and whether a liner is used.

During mechanical dredging the operator must be careful not to hit the sides of the barge with the bucket, which can rip the fabric. Also, the operator must be careful not to drop the dredged material from too far above the barge. The falling dredged material can rip the weaker nonwoven fabric liners. These restrictions will reduce the dredging production rate. For example, at Marina Del Rey, dredging production was reduced from an estimated rate of over 300 m³/hr to 150 m³/hr. To reduce the potential for debris to rip the containers, debris removal with a large open screen or grid is recommended.

It is possible to fill GFCs hydraulically. Because hydraulic filling can be accomplished through a few small openings, little contact with the contaminated material by laborers is experienced during the sewing process. The sewing process is much faster because only a few small opening(s) must be sealed.

Hydraulic filling of GFCs with mildly creosote-contaminated, fine-grained dredged material was used at the Port of Oakland in 1994 (Fowler, Sprague, and Toups 1995). The sediments were mechanically dredged, placed in a compartmented barge, and rehandled with a submersible pump with a water jetting ring to pump material into GFCs resting on the dock (Figure 3). The material in the GFCs was allowed to drain to a consistency (65 percent solids) such that a front-end loader could transfer the sediments into a dump truck for transport to an approved landfill. Care must be taken during hydraulic



Figure 3. Hydraulic filling of a GFC at the Port of Oakland

filling to ensure that excess pressure from the pump does not burst the geosynthetic fabric container.

Placement of geosynthetic containers is also potentially complicated. If tight tolerances are placed on the exact location where each container is to be placed, properly positioning the barge and keeping it on station during the 30 sec to several minutes required for the container to exit the barge is not a trivial matter. In sheltered waters it is possible, but in the open ocean with conventional equipment, it will be difficult to precisely position the containers with conventional tug/barge arrangements.

At Red Eye Crossing the barges were anchored, after using survey equipment to locate them within a tolerance of a few feet. For the Marina Del Rey project, placement took place in the sheltered waters of Los Angeles/Long Beach Harbor. Meeting the tight positioning tolerances (about 10 m) required repositioning the large tug used to tow the barge, and the addition of a second smaller tug. This method of operation is probably not practical in the open ocean. Towed barges typically have long lines between the tug and the barge. Lengths of 100 to 200 m (with lengths increasing as seas become more severe) are common. Positioning the barges to tolerances greater than one barge width laterally (10 to 15 m) is difficult. To maintain steerage for a towed vessel in the open ocean, the barges have to be moving forward, making positioning difficult particularly in light of the unknown time for the containers to exit. Achieving tight positioning tolerances with GFCs in the open ocean may require specialized or modified equipment, such as powered barges that open to near-full bin width in a relatively short time.

Experience Using GFCs at Red Eye Crossing, Louisiana

Red Eye Crossing, located on the lower Mississippi River at Mile 175, is the most difficult crossing for the Corps' New Orleans District to maintain. An estimated 2 million m³ of dredged material was removed each year to maintain the 12-m-deep channel at this location. Model studies showed that underwater dikes should constrict riverflow, making the channel more self-scouring and thus substantially reducing dredging requirements. Concerns over the potential safety aspects associated with fuel barges running aground on rock dikes led the New Orleans District to construct soft dikes made from sand-filled GFCs.

Approximately 560 GFCs (14 to 44 m long, with a perimeter of 14 m) were placed in water depths of 13 to 21 m in currents up to 1.8 m/sec. The GFCs were used to construct dikes 150 to 550 m long. Dike crest width was 3 m, and with 1V:2H side slopes, heights varied from 4.5 to 9 m, producing base widths of 20 to 40 m (Figure 4). Sandy material with a D_{50} of 0.5 mm was placed in the containers, which held up to 380 m³ of material. The AOS of the material that was used corresponded to a sieve size of 70 to 30 (that is, 0.2 to 0.6 mm) (Duarte, Joseph, and Satterlee 1995).

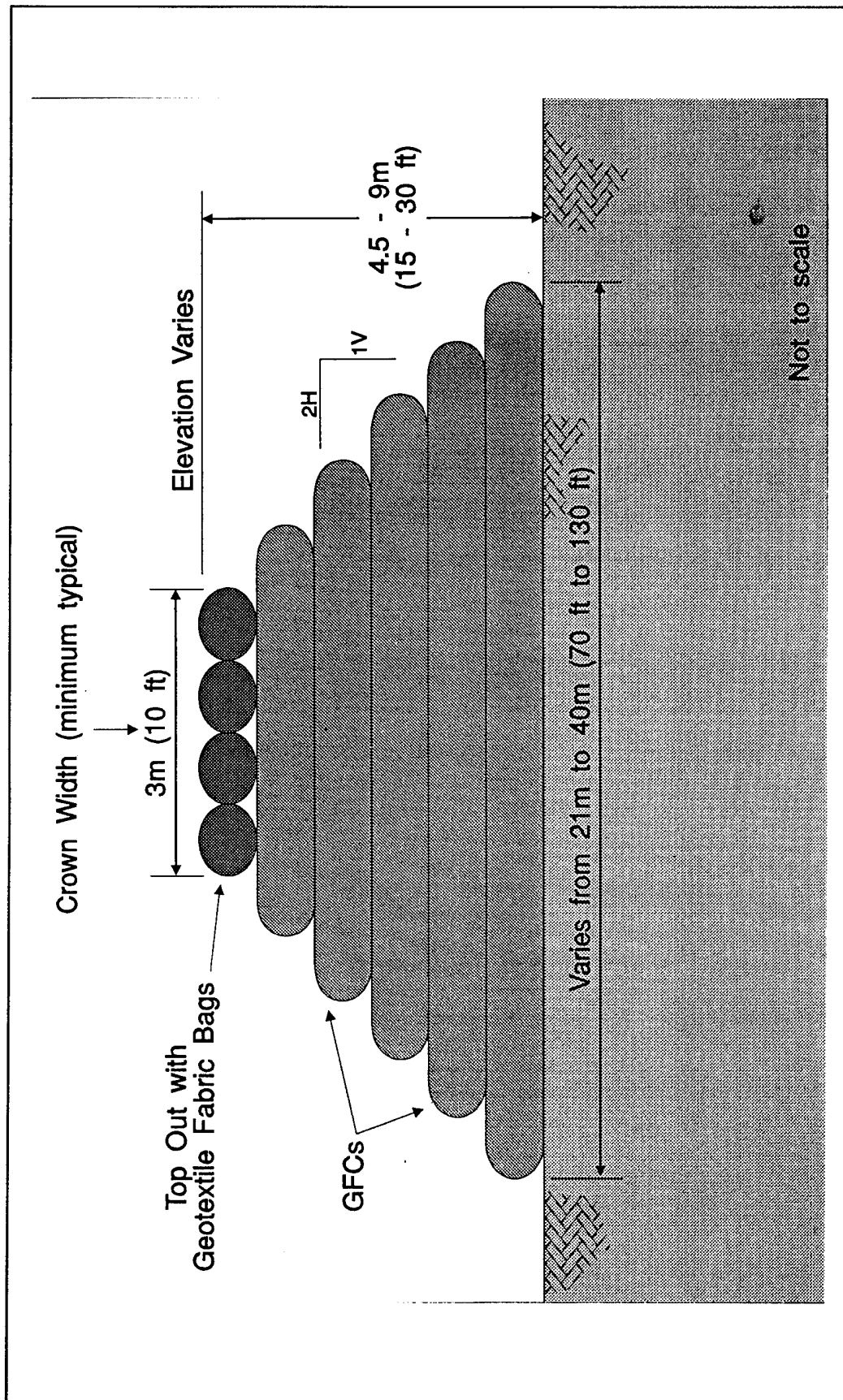


Figure 4. GFC soft dike structure used at Red Eye Crossing

GFCs secured in the barges were filled with sand using a front-end loader, which operated from a supply barge anchored adjacent to the work barge. After the GFCs were filled to 75 percent capacity, it took approximately 15 to 20 min to close the GFCs by sewing. Modified split-hull barges with a hull opening of 3 m, or 75 percent of the bin width (false bulkheads were added to reduce bin width), were used to deploy the GFCs. It took 3 to 5 min to release the GFCs from the barge. As noted above, the barges were anchored in place with positions accurately surveyed. Barge positions were offset to account for GFC displacement caused by currents of up to 1.5 m/sec. The contractor was able to accurately place the containers, as evidenced by bathymetry and side-scan sonar surveys during and after construction.

In addition to two conference papers that describe the project (Fowler and others 1995a; Duarte, Joseph, and Satterlee 1995), a report is being prepared by the New Orleans District. Additional information on the project from a geotechnical viewpoint is available from Mr. Frank Duarte (CELMN-ED-FD, (504) 862-1014). The operations point of contact on the project is Mr. James Scott, (504) 862-2905.

Experience Using GFCs at Marina Del Rey, California

In November and December 1994, 40,000 m³ of silty sand contaminated with hydrocarbons and heavy metals (chromium, lead, and zinc) were mechanically dredged from the entrance channels at Marina Del Rey and the adjacent Ballona Creek entrance and placed into barges containing GFCs (Figure 5) (Fowler and others 1995b, Mesa 1995). The filled GFCs were placed in the shallow-water habitat area of Los Angeles/Long Beach Harbor. An inner liner capable of retaining 100 percent of fine particles retained on the No. 230 sieve (0.0625 mm) was a project requirement. The 16-oz (0.45-kg) nonwoven liner used on the project had an AOS that corresponds to a sieve size of 100 to 170 (0.149 to 0.088 mm).

The contaminated sediments were placed in two 2,060-m³ split-hull dump scows that were specially modified for this project. The barges were modified to meet the contract specification (based on limited small-scale model tests conducted at WES) requiring the barge hull opening to be at least one half the bin width. Barge modifications included construction of false sides to reduce the width of the bin to 6.7 m (barge bin length was 54 m with an overall height of 6.7 m). The width of the split hull opening was about 3.55 m, thus meeting the contract specification. In addition, end plates were installed at both ends of the scow bin to prevent the geosynthetic fabric from bulging at the ends and catching on the hydraulic rams. Side walls in the bins were ground down with a metal grinder to remove burrs that could tear the geotextile fabric. Cost of modifying the barges was \$250,000.

The GFCs initially used were 54 m long by 27.4 m in perimeter, with a capacity of approximately 3,000 m³. The GFCs were constructed with double



Figure 5. Filling a GFC at Marina Del Rey

liners—an outer woven polyester liner for strength and in inner nonwoven liner to provide filtration.

The inner 16-oz nonwoven fabric made it difficult to handle the containers, especially when they were saturated (for example, by rain). At the end of the filling process, the contractor had to sew up both liners; thus, the sewing process took about 2 hr. The second container also increased the time to assemble the containers initially and to deploy the containers in the barge. It was proposed that an 8-oz (0.23-kg) liner be used, since it is much easier to handle than the 16-oz liner. However, the ability of the 8-oz liner to prevent the migration of fines had not been tested, and thus it was not used for this project.

The first load consisted of $1,400 \text{ m}^3$ of sediment placed in the $2,060\text{-m}^3$ scow, which filled the hopper to within 1.5 m of the top. The scow was taken to the placement site and opened fully, but the GFC would not discharge from the hopper. Some combination of arching, apparent cohesion caused by incomplete saturation, and a geotextile that pulled taut over the opening at the bottom to confine the soil and prevent movement is suspected of causing the

container to lodge in the scow. Unsuccessful attempts to free the container included bumping the scow to shake the GFC free, moving the jaws of the scow against the container to induce movement, and surcharging the container from the top to force the sand mass out. These attempts occurred over a 6-day period, after which the GFC was dislodged by injecting large quantities of water into the contained dredged material. Water was injected through diffuser pipes using the 7.6-m³/min pump of a Los Angeles County fire boat; water injection continued for about 2 hr before the GFC dislodged.

In the second barge, the volume of sediment was reduced to 460 m³, and the perimeter length of the container increased to 37 m to provide extra fabric at the bottom to allow free-fall of material into this "pouch" and facilitate container discharge from the hopper. This container discharged without incident. The volume of subsequent loads was increased by 150 to 230 m³, up to a load of 1,000 m³. At this point the containers showed a tendency to hang in the barge (as evidenced by longer exit times). Thus, the maximum practical volume was limited to about 1,000 m³.

Initially, the barges were lined with a polyester geosynthetic fabric to improve the ability of the GFCs to slide out of the barge; however, a relatively high coefficient of friction was thought to exist between the wet polyester bag and the polyester liner. As a result, the barge liners were removed after the problem with the first container was encountered. The consensus was that the placement problems were caused by the sandy nature of the material, not the liner. The material dredged from Marina Del Rey was fine sand with only 7 to 8 percent fines.

Because there were tight tolerances on where the containers had to be placed, positioning of the barge prior to releasing the GFCs at the shallow water habitat site took longer than originally expected—30 min to 1 hr. The barges were towed to the site; then, the tug released the tow and tied up alongside the barge. A second smaller tug tied up to the other side to help position the barge. The 2,000-m³ barges had a good deal of sail area and were difficult to position in high winds.

The container placement operation was monitored by divers and video, and a side-scan sonar survey was planned at the end of the project. However, the Port of Los Angeles was also disposing of contaminated material from inside the harbor in the same shallow-water habitat while the containers from Marina Del Rey were placed. This placement was by conventional bottom dumping. The mix of materials made it difficult to observe details of bag placement.

The added complexity at Marina Del Rey resulted in a total cycle time of 19 to 22 hr for dredging/placement operation. This time is broken down as follows:

Load and install containers in barge	2 hr
Dredging	6-7 hr
Sew containers	2 hr
Tow from Marina Del Rey to Port of Los Angeles	4-5 hr
Dispose of material	1 hr
Tow from the Port of Los Angeles to Marina Del Rey	4-5 hr

The time for conventional dredging was estimated to be 14 to 17 hr.

The slow pace of dredging and placement, approximately 1.5 bargeloads per day (roughly 1,500 m³ per day), resulted in the contractor removing only 42,000 m³ during the 40-day dredging period. If the use of GFCs on the project had not been required, production rate would have doubled, allowing over 85,000 m³ to be dredged.

Unit cost of the entire project, including the cost of the GFCs (\$26,000 per container including both the inner and outer liners), mobilization/demobilization, and actual dredging was about \$100/m³. If the project had used conventional split-hull barge placement, the unit cost for dredging alone would have been in the range of \$9 to \$13/m³. Assuming that 80,000 m³ had been dredged in the same 40-day time period with conventional placement, the mobilization/demobilization unit cost would have been in the range of \$10 to \$13/m³. Thus, the total unit cost for conventional placement on this project would be approximately \$20 to \$26/m³.

The Los Angeles District point of contact for additional information about the Marina Del Rey Project is Mr. Anthony Risko, (213) 894-5644.

Other Considerations for Using GFCs with Contaminated Dredged Material

While not all of the following issues are directly related to site-capacity issues for using GFCs, they should be addressed prior to using GFCs. One issue is how long after placement must capping commence. For most contaminated sediment projects, capping must be begun within 2 to 4 weeks. If capping of material placed in GFCs can be delayed longer, additional operational flexibility will be provided.

High GFC placement densities (that is, very small gaps between individual GFCs), estimated at greater than 90 percent, were achieved in the submerged dikes created at Red Eye Crossing with anchored barges. However, the

experience at Marina Del Rey showed that, even with two tugs operating inside a harbor, achieving 9-m gaps between GFCs was time consuming. To make reasonable estimates of site capacity using GFCs for contaminated sediments in open ocean sites, values of GFC placement density are needed. Practical estimates of open ocean positioning accuracy are needed, combined with field evaluations to provide placement density data.

Wave forces on GFCs, particularly in shallow water (approximately 20 m and less), should be considered. The potential for a hurricane or northeaster to move the containers prior to capping should be investigated.

While poor weather causes problems for many dredging operations, those projects using GFCs are particularly susceptible. For example, rain increases the difficulty of handling the fabric. Moderate wind and waves make precisely positioning tug-powered GFC barges more difficult. High winds, waves, and even moderate currents will make precise positioning of split-hull barges with conventional tugs essentially impossible.

Summary

GFCs can be used for contaminated dredged material placement. However, the high costs associated with using GFCs limit their use to those projects where savings in cap volume justify their use. Also, if space or site capacity is limited, containers could be worthwhile. Other applications would be those projects where more conventional options are either unavailable or extremely expensive.

Using GFCs to reduce water column impacts is probably not warranted for most projects because, in most instances, water column impacts (even with contaminated sediments and normal placement operations) are not a problem. For those projects where water column impacts are an issue, it is possible that just the outer strength container would sufficiently reduce dispersion to meet water quality standards. If a nonwoven liner is required, the 8-oz liner (which is easier to handle) may be sufficient, as opposed to the 16-oz liner used at Marina Del Rey. Testing conducted to date on migration of fines and contaminants through the fabric does not reflect actual field conditions and should be done in a more rigorous fashion.

Costs of placing dredged material using GFCs are substantially higher than conventional mechanical dredging and bottom dump barge placement because of the cost of the GFCs, labor, land facilities, and barge modifications. The cost of the GFCs (including the inner liner) is approximately \$13 to \$16/m³. The GFC manufacturer estimates that the use of GFCs increases the cost per cubic meter approximately \$33 to \$40 over the normal dredging and placement cost. For the Marina Del Rey project, the cost increase from using GFCs was approximately \$65 to \$78/m³. At Marina Del Rey (the first time GFCs were used for contaminated dredged material placement), the final unit cost (including mobilization/demobilization) was nearly \$104/m³. Note that these are

rough cost estimates; actual cost estimates for a specific project should be developed in close consultation with GFC manufacturers and dredging contractors.

The entire process of assembling, placing in the barge, unfolding, securing, and then sewing closed the GFC after filling is time consuming and labor intensive. The added time for the process could be minimized if a sufficient number of barges, tugs, and staff are available, but will probably be at least 1 to 2 hr.

Filling the GFC is relatively straightforward, but can take longer than normal mechanical dredging. The GFCs (particularly the weaker liners) can be ripped by the force of the dredged material if it falls from too far above the barge. Thus, the care required when handling the material often increases the dredge cycle time. Also, it should be noted that, to get the maximum benefit from the GFC placement, the containers have to be placed precisely, with horizontal positioning tolerances on the order of a few meters. Accomplishing this in the open ocean will be very difficult, and either the cycle time will be increased considerably or the density with which the containers can be packed will be reduced.

Using GFCs for placement of contaminated dredged material is a recent development with limited experience. Additional information is needed on the environmental effectiveness and operational feasibility of this option. Future demonstrations and evaluations should include efforts to gather additional information on the following:

- a. Methods for safe and efficient exit of the GFCs from the barge.
- b. Effectiveness of GFCs in preventing dispersion of suspended solids.
- c. Effectiveness of GFCs in inhibiting entrainment of water during descent.
- d. Quantity and quality of water that is released from the GFCs in the long term.
- e. Potential for bioturbation to degrade the GFC.

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